

The HVAC Service Assistant
A Tool for Reducing Electrical Power Demand and Energy Consumption



Commercial



Residential

Introduction

Traditionally, verifying the success and impact of HVAC system tune-ups on reliability, safety, and energy efficiency is difficult and expensive to accomplish. Today, this is no longer the case. Practical and affordable means exist that will change HVAC field service and its perceived value in the marketplace.

The HVAC Service Assistant is an award-winning instrument and reporting system that helps better manage the technical aspects of HVAC field service which leads to improved equipment performance and energy efficiency. It recently won the [2003 AHR \(Air-Conditioning, Heating and Refrigerating\) Expo Innovation Award](#) in the highly competitive “Instruments, Tools and Software” category.

Developed by Field Diagnostic Services, Inc., current applications of the instrument are the servicing of air-conditioners (including heat pumps in cooling mode) for commercial buildings (e.g. packaged rooftop units), and residences (e.g. standard split-systems). Research and engineering work is underway to expand Service Assistant capabilities to include heat pumps in heating mode, and commercial refrigerating systems. These are logical extensions of the technologies embedded in the Service Assistant – which can be applied to most types of refrigerant vapor-compression cycle equipment.

HVAC Field Service

When air-conditioners operate without effective maintenance, their performance degrades and the likelihood of higher electric power demand, wasted electric energy, and damage to components like compressors increases. However, a sense that all is well may exist because cool air is still flowing into a building or home. Unfortunately, cool air is not a reliable indicator of air-conditioner health and performance. Much can go wrong before the cool air stops flowing.

Field service technicians are on the frontline in the effort to keep equipment operating efficiently and reliably. Equipment performance is directly impacted by the work they do, and is sensitive to how well they do it. Their work is important. But despite the best of intentions, too many technicians still try to identify and diagnose equipment performance problems relying on folklore, rules-of-thumb, an incomplete understanding of how equipment works, and a limited toolbox. They rely upon visual signs of trouble, or a few simple physical measurements to guide them. Their observations, data, diagnoses and thoughts in the field are recorded (at best) on a piece of paper. This manual low-tech approach to the field service process is ineffective, outdated, and overly dependent upon the experience, personality and capability of the technician on the job. It provides no practical way for technician supervisors, building owners, facility managers or energy providers to know how well equipment is operating, what maintenance is required, what energy-saving opportunities exist, and whether service work is performed properly. The service process is open loop and poorly documented. At a time when the U.S. HVAC contracting industry is experiencing an alarming shortage of trained technicians, and is grappling with the challenges of losing its best talent to retirement, without a remedy the problem could get worse before it gets better.

The HVAC Service Assistant

The Service Assistant was designed to address the field service problems outlined above. In this technology report, we will explain how the instrument helps technicians...

- inspect units, and collect field data more easily and accurately.
- analyze performance and diagnose problems on-the-spot – often uncovering hidden problems.
- estimate efficiency and potential energy savings accurately.
- document their work and report results to supervisors, managers and customers.

With Service Assistant reports in-hand, energy savings can be assessed, smart maintenance and repair decisions can be made, and service quality can be verified. These and other benefits of the Service Assistant will be presented in this report, along with key features – those presently available and those coming in 2003. The status of reviews of our key performance estimation technology by independent experts will also be provided.

Understanding the Service Assistant

The Service Assistant integrates into a single package a...

- multiple pressure and temperature measurement system.
- handheld computer with application-specific software.
- standard refrigerant manifold with three hoses (red, yellow, and blue).



This package is as easy to carry as a technician's standard manifold gauge set. The instrument is easy to use and employs a handheld computer (i.e. a Palm OS® device) as its user interface. All aspects of the instrument are controlled through the user interface. The software on the computer allows the technician to configure and operate the instrument as required by the tasks at-hand.

Inspecting Equipment and Collecting Data

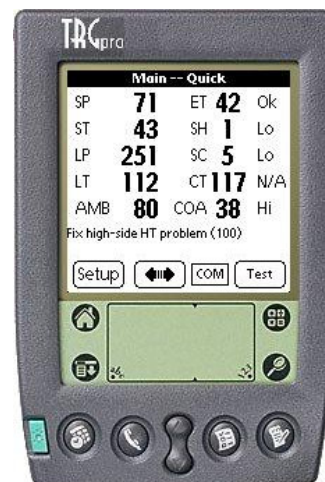
An effective service process begins with equipment inspection and collecting baseline data. The Service Assistant makes technicians more productive from the very beginning by making useful documents available at a job site, such as work procedures, service forms, and job orders – all in electronic form. Customizable task lists help guide technicians through an equipment inspection and also help standardize the process. Forms and other service documents provide a way for them to input data or notes about a job, such as equipment makes, models and serial numbers; refrigerants used; and their observations on the condition of equipment.

With respect to baseline data, the standard Service Assistant measures two pressures and three temperatures in order to assess air-conditioner health and performance:

- suction line pressure (SP) and temperature (ST)
- liquid line pressure (LP) and temperature (LT)
- outdoor ambient air temperature (AMB)

In addition to the three temperatures mentioned above, the Service Assistant also provides a means for technicians to manually input return air wet bulb temperature, usually measured with a separate temperature-humidity probe. Knowing the indoor wet bulb temperature and the outdoor ambient temperature defines the operating conditions of the air-conditioner.

Inside the Service Assistant are two pressure sensors that replace the manually-read mechanical gauges on the standard refrigerant manifold. Two of the standard hoses are used to deliver pressurized refrigerant to the manifold and sensors (i.e. red hose connects to liquid line; blue hose connects to suction line). The red hose has a check valve at the inlet to minimize refrigerant loss when disconnecting from a system. The third (yellow) hose is for adding or removing refrigerant. A wire harness connects three external temperature sensors to the Service Assistant.



Using its integrated pressure and temperature measurement system, the Service Assistant electronically measures the refrigerant pressures and temperatures relevant to quantifying air-conditioner performance. After measuring and inputting the return air wet-bulb temperature, the technician simply connects the Service Assistant hoses (as usual) and temperature sensors to the correct refrigerant lines. The data is automatically collected, analyzed, and updated every few seconds. By pressing a button on the computer's user interface, the information is saved for future reporting.

Analyzing Equipment Performance

After collecting the pressure and temperature data, the Service Assistant automatically analyzes the air-conditioner's performance. It will detect and diagnose problems (i.e. component faults), if they exist, using analytical models and expert knowledge incorporated in the handheld computer software. These proprietary software algorithms are based on proven field-tested models of air-conditioner faults. By employing software to test the air-conditioner and evaluate the data, the Service Assistant reduces subjectivity and human errors – improving analysis consistency and accuracy. If a fault is found, a diagnosis is automatically offered and explained to the technician. As we explain how performance is analyzed by the Service Assistant, it should become clear that expecting a technician to manually perform the same tasks, on every unit, is not practical on a large scale. Yet without these analyses, one cannot obtain quantitative knowledge about actual equipment performance – good or bad.

To analyze performance, the Service Assistant compares the value of performance measures, calculated from measured data and based on the particular air-conditioner under test, against a Benchmark Performance Model. The Model embodies well-established industry norms (targets) for healthy equipment performance that balance the three competing aspects of air-conditioner operation – capacity, efficiency, and reliability. The performance targets are reasonably achievable by any air-conditioner. Defined in the table below are the four performance measures. The Service Assistant determines if a problem exists, and offers a diagnosis if one is found, based on how well actual performance measures for a unit compare to the targets determined by the Model for the current operating conditions.

Performance Measure	Symbol	Value Determination
Evaporating Temperature (Evaporator)	ET	Refrigerant P-T chart and measured suction line pressure (SP)
Superheating Level (Suction Line)	SH	Measured suction line temperature (ST) minus ET
Subcooling Level (Liquid Line)	SC	CT* minus measured liquid line temperature (LT)
Condensing Temperature Over Ambient (Condenser)	COA	CT minus measured outdoor ambient air temperature (AMB)

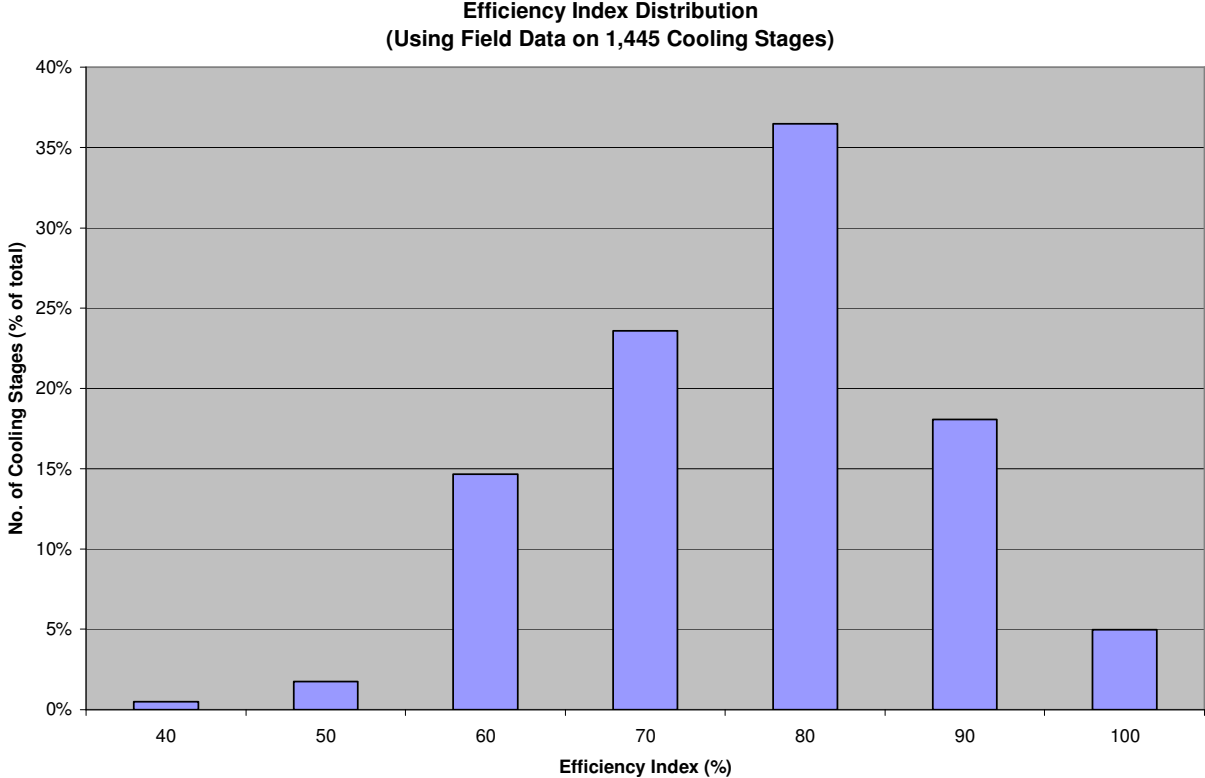
* Condensing Temperature (CT) is an intermediate quantity often calculated by technicians using the refrigerant P-T chart and measured liquid line pressure (LP). The Service Assistant displays the value but does not use it directly to determine if a problem exist.

It's important to note that the Service Assistant works well on all air-conditioners down to an outdoor ambient temperature of 65°F. However, for air-conditioners with fixed-orifice-type expansion valves, the Service Assistant provides the unique capability of being able to work at cooler temperatures – down to 55°F. Traditional methods are generally limited to 65°F. With the Service Assistant, inspections can be performed earlier in the spring and later in the autumn, as well as in the early mornings and late afternoons in climates with high daily temperature variability.

Estimating Energy Efficiency and Potential Savings

In addition to detecting and diagnosing faults, the Service Assistant computer software also estimates an Efficiency Index (EI) and a Capacity Index (CI). The EI is a percentage estimate of actual equipment efficiency relative to the Benchmark Performance Model (EI = 100%) for the existing operating conditions. For example, an EI of 80% means a 20% efficiency improvement could be realized, if the equipment was properly serviced and problems were corrected. It is not unusual for the Service Assistant to find working air-conditioners that have an EI of 70%. Some working units can have EI's of 50% or less! This commonly happens when refrigerant charge levels are extremely low. We constructed the distribution plot below to show the approximate percentage of cooling equipment usually found at each EI level during inspections. This is field data collected on 1,445 air-conditioning cooling stages, and stored in our Web Service database. The plot provides a sense of what one finds in the field when using the Service Assistant.

When we speak of efficiency, we are referring to the total heat absorption rate (BTU/hr) from the conditioned space divided by the electrical power demand (W) of the air-conditioning unit – the so-called Energy Efficiency Ratio (EER). To calculate the EI, the Service Assistant estimates the EER for the measured test conditions, and the EER for the Benchmark Performance Model. Dividing the actual EER by the model EER, and expressing the numerical result as a percentage, gives the EI for the air-conditioner.



Knowing the EI not only provides an estimate of efficiency, it also allows the Service Assistant to estimate the annual cost of the inefficiency in a straightforward manner. For example, if a 20-ton, 10 EER commercial air-conditioner is found to have an EI of 70%, its inefficiency is 30%. A healthy 10 EER air-conditioner will demand about 1.2 kW of electric power per ton of cooling capacity. If the unit operates 1,200 hours during the course of a year, it will consume about 28,800 kWh (= 20 tons X 1.2 kW/ton X 1,200 hours/year). An inefficiency of 30% means an additional 8,640 kWh are consumed and wasted. Assuming a utility rate of 10¢ per kWh, 8,640 kWh of wasted energy costs \$864. Extra demand charges may also occur. This energy and money could be saved, if the air-

conditioner's problems were fixed and it was well-maintained the rest of the year. The Service Assistant performs these calculations automatically and documents the results.

It is important to note that because the Benchmark Performance Model optimally balances capacity, efficiency and reliability, it is possible for an air-conditioner's EI or CI to exceed 100% – but this is not desirable. Exceeding the Benchmark by improving one aspect of operation has potential negative consequences that outweigh any perceived benefits.

Patent Filed for Operating Parameter Estimation Technology

The ability to quickly estimate efficiency and capacity in the field, based on real data, is a powerful innovation for the HVAC service industry. As a result, Field Diagnostics has submitted a U.S. patent application for this technology.

In addition, because the technology's usefulness relies upon the quality of the estimates it computes, we have asked a few experts to review the patent application (plus other supporting documents) and provide their independent technical assessment of the technology. The first assessment we have received is from John House, Ph.D. of the Iowa Energy Center. Interested readers will find Dr. House's October 25, 2002 memorandum to Field Diagnostics in the appendix of this report. In the coming months, we are expecting additional independent expert assessments.

Until the patent becomes public, Field Diagnostics will gladly provide the existing application and related information to select individuals and organizations that are willing to sign a proprietary information non-disclosure agreement. Please contact us directly (see report cover sheet) to make such a request, or to inquire about the availability of additional expert assessments.

Documenting and Communicating Results

Throughout the entire process of inspecting air-conditioners, collecting data, and analyzing performance, standard reports containing field notes, test data and analysis results are stored on the Service Assistant's handheld computer (when saved by the technician). If a technician visits multiple job sites in one day, the computer easily documents and keeps track of each and every site report. And if there happens to be multiple air-conditioners at some of the sites – a dozen rooftop units at a retailer for example – the computer handles multiple units just as easily.

While at a job site, the technician may wish to provide a hardcopy report to the customer or building owner. The handheld computer can print report cards in the field directly on a low-cost portable printer.

Although printed reports in the field may be needed for some jobs, the real power of the Service Assistant comes when its Internet communications capabilities are used. Saved reports can be uploaded to a web server, over the Internet, using a standard telephone line and modem. It is recommended that a technician do this at least once a day to make sure the data is safe and secure. Once the reports are on the server, additional analyses can be performed, and the reports can be viewed by anyone with authorized access. Field Diagnostics offers a toll-free Web Service for the Service Assistant, although users are free to choose how they wish to manage and report their data – including the simple approach of syncing the handheld computer (i.e. exchanging data) with a standalone desktop computer back at the office.

Realizing the Benefits

Numerous features and benefits of using the HVAC Service Assistant and Web Service have already been discussed in this report. However, three major benefits deserve further emphasis:

- make smarter maintenance and repair decisions.
- verify service quality.
- reduce electrical power demand and energy consumption.

Making Smarter Maintenance and Repair Decisions

If an air-conditioner is operating with degraded performance, knowing the impact on energy consumption and utility bills on-the-spot is a unique benefit of the Service Assistant. A homeowner can see for example, the \$100 in maintenance work they are avoiding is probably costing them more in terms of higher electric utility bills. After seeing a Service Assistant report, it's reasonable to expect that they will believe the work makes sense, instead of wondering if the technician is being truthful about the performance of their air-conditioner. And if their air-conditioner is working fine, it's nice to know that too.

Helping facility managers, and owners prioritize service work is another benefit provided by the Service Assistant. Limited resources typically exist for the maintenance and repair of commercial air-conditioning systems. Yet, for a commercial organization (e.g. a national retail chain), it is common to have a large number of air-conditioning units located at various sites. How should limited resources be applied to a portfolio of units so that the effectiveness of service actions is maximized? Which units are working fine and don't require any maintenance? Without Service Assistant reports, it is hard to know. But with Service Assistant reports, one can be smarter about which units to attack first – those with the lowest efficiency or those operating in such a manner that components are likely to be damaged (e.g. compressor failure due to low superheating levels). Without the performance analyses and diagnoses provided by the Service Assistant, deciding which units need more attention than others is rendered to guesswork.

Verifying Service Quality

Earlier in this report, it was stated that an effective service process begins with equipment inspection and collecting baseline data. But in order to verify service quality, data must be collected after service work is performed as well. Collecting this data is a great way for the technician to verify that his or her actions were effective and an air conditioner is now performing as designed. If performance is within tolerances of the Benchmark Performance Model, the Service Assistant will say “no faults detected”. If not, the technician will know something is still not right and needs attention. Before and after data is also useful to technician supervisors – by comparing before and after data on many jobs, they can better assess the productivity and skill levels of their technicians, and see where more training is needed. This can improve future service quality.

Another situation where service quality can be improved is utility incentive programs. Utilities often have incentive programs for new building construction to encourage installation of higher efficiency (i.e. SEER) equipment, and incentive programs for existing installations to encourage upgrades to higher SEER equipment. The Service Assistant is useful in either case to verify and document the new equipment is working properly, and to baseline its performance (i.e. EI and CI) from day one.

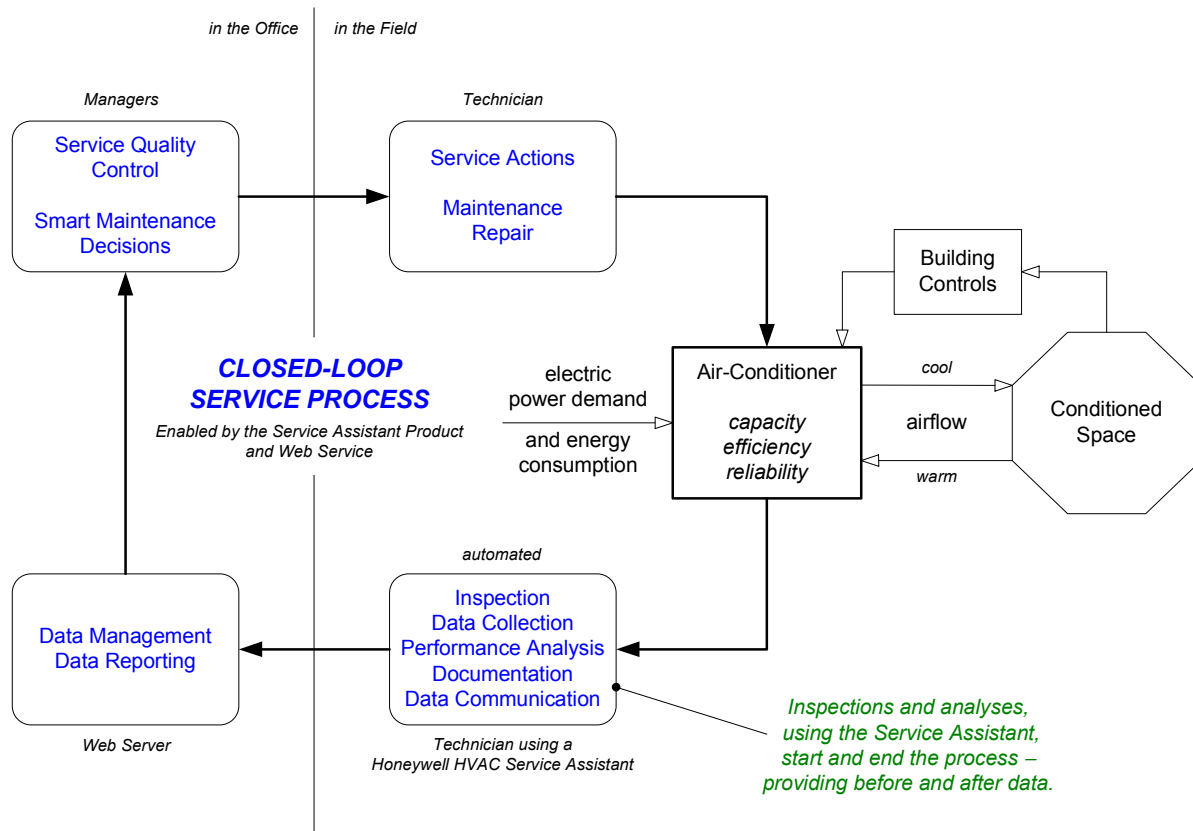
Having field service work well-documented and reported provides a refreshing openness to the service process. This openness helps build trust between those who service, and those who own equipment or pay the bills. Without the quantitative proof of performance provided by the Service Assistant, home and business owners simply must trust the technician. But with the proof, all parties can know the facts and can make rational decisions. The Service Assistant enables a closed-loop service process by providing necessary feedback in the form of field reports. The diagram on the next page shows the concept and visually represents the overall process we have described in this report.

Reducing Electrical Power Demand and Energy Consumption

Electrical power demand and energy consumption by HVAC equipment contributes significantly to overall electricity usage by a community. In addition to operating costs born by users, this usage also impacts utility companies and the environment, especially when electricity needs grow and expensive new power plants must be built. We believe the closed-loop service process enabled by the Service Assistant and Web Service is the most effective and reliable way to achieve, maintain and assure design efficiencies – thus minimizing electricity usage by installed equipment.

In utility conservation and incentive programs, the Service Assistant can provide energy savings estimates, as well as the before and after data to prove that service work was done properly, and a rebate is valid. The inspection and data collection capabilities of the instrument also provide valuable information about the installed base of equipment in a geographic area, such as their makes, models and operational performance. This can help guide programs where replacement of older equipment is emphasized.

We see the Service Assistant and Web Service as a powerful solution to HVAC service problems, and look forward to working with service contractors, facility managers, and energy providers to continually improve equipment performance.



Our Work Continues

Field Diagnostics continuously improves the Service Assistant and Web Service, and expands capabilities into more applications, through in-house research and engineering efforts. Developments expected to be available in 2003 are:

- *Performance Tuning Feature.* Will provide guidance as to what service actions could improve efficiency, even though no problems (faults) were detected.
- *New Heat Pump Application.* This application will provide diagnostic capabilities for heat pumps in heating mode.
- *New Commercial Refrigeration Application.* This application will provide diagnostic capabilities for commercial refrigerating systems.

Iowa Energy Center Memorandum

To: Field Diagnostic Services, Inc.

From: John M. House, Ph.D.
Iowa Energy Center

Date: October 25, 2002

Subject: Review of the Technology Described in the Patent Application
“Estimating Operating Parameters of Vapor Compression Cycle Equipment”

At the request of Dr. Todd Rossi of Field Diagnostic Services, Inc., I have reviewed the technology that forms the basis for the patent application titled “Estimating Operating Parameters of Vapor Compression Cycle Equipment.” This memorandum provides an overview of the technology, as I understand it, and summarizes my assessment of the technology.

Overview

The technology described in the patent application enables the performance of vapor compression equipment to be characterized in relation to the performance that would be expected if a piece of equipment was operating properly (referred to as the benchmark performance). The actual performance is quantified by the capacity and coefficient of performance (COP) of the unit under consideration using temperature and pressure measurements (operating parameters) that are commonly made by service technicians in the field. Certain assumptions are made that enable the calculation of the performance parameters (capacity and COP).

The benchmark performance is also quantified in terms of the capacity and COP of the unit under consideration; however, the performance parameters are calculated using values of operating parameters that experience has shown to be typical for a normally operating unit (i.e., operating in the absence of faults, such as an undercharge of refrigerant). Thus, the operating parameters for determining the benchmark performance are set, rather than measured.

The actual performance and benchmark performance are determined for the same driving conditions (ambient and return air conditions) to enable comparison of the performance parameters. By taking the ratio of the actual capacity to the benchmark capacity, the capacity index (CI) is determined. By taking the ratio of the actual COP to the benchmark COP, the efficiency index (EI) is determined. CI and EI are then used to estimate the annual savings in operating costs that could be achieved by servicing a unit so that it achieves its expected performance. The estimated savings can be used to determine whether the benefits of servicing a unit outweigh the costs.

Assessment

Having reviewed the patent application, I have concluded the following:

- The technology is based on measurements that are commonly made by service technicians in the field.
- The assumptions and analysis used to determine the capacity index, efficiency index, and annual operating costs associated with not correcting an operating deficiency are, in my opinion, sound. There are two assumptions, however, that I feel could be better justified or explained. The first applies to the superheat correction to the input power that is needed when the actual superheat varies from the ARI standard superheat. The patent application explains why a similar correction to the mass flow rate is justified; however, a similar justification for the input power is not provided. Even if this justification is implicitly obvious, an explicit statement of the justification seems appropriate.

The second assumption that I feel could use additional explanation concerns the approximation that the term \overline{UA}/\dot{m} does not vary significantly. It was unclear whether this is broadly accepted in the industry, or based on the experience of the technology developers. It would be helpful to have some indication of the degree of variation of this term and/or the sensitivity of the enthalpy calculation to this variation.

- The algorithm requires refrigerant properties and compressor performance characteristics in addition to the measurements that must be made. It is my understanding that both the refrigerant properties and the compressor characteristics are readily obtained. Thus, encoding the algorithm described in the patent application into a commercial tool should not present any significant difficulties for the technology developers.
- Supplemental documentation provided to me with the patent application indicates that data collected at Purdue University have been used to validate the soundness of the technology. The range of conditions available from laboratory testing, both in terms of the driving conditions and the operating state of the unit (i.e., operating normally or in the presence of several faults or varying severities), is very extensive. The only potential shortcoming of the validations is that it is unclear how many separate units were used to produce the data. In my opinion, the broad range of testing conditions and the quality of the laboratory measurements outweigh the shortcomings associated with testing only a small number of units.
- Tools with the capability to estimate energy savings associated with servicing vapor compression equipment are clearly needed. In my opinion, the technology described takes us to the point where this is now a reality.